Zero-Emissions Aircraft?

NASA Environmental Compatibility Research Workshop III

Scenarios for Aviation's Growth: Opportunities for Advanced Technology:

"Zero Emissions" Aircraft

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Zero-Emissions Aircraft?

- Present Study Status and Results
- Compare Emissions from a “conventional” baseline versus alternative systems
- Background
  – Respond to some preliminary numbers from Waitz & Pannathur, MIT
  – Try to go into additional detail, address technology issues for promising concepts

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Zero-Emissions Aircraft?

<u>"Baseline" Aircraft Used for Studies</u>

- **Basis for Comparison: Advanced Aircraft Derived from NASA Scenario-Based Review (1997)**
  - **Max. take-off mass ≈ 344,000 lb**
  - **Typical operating empty mass ≈ 168,600 lb**
  - **Max. fuel capacity ≈ 92,550 lb kerosine**
  - **Takeoff thrust ≈ 54,900 lb per engine(2)**
  - **Cruise thrust ≈ 16,100 lb**
  - **Design range ≈ 6500 nmi**
  - **Passengers ≈ 325**
  - **Length ≈ 221 ft., Wingspan ≈ 194 ft.**
  - **Cruise L/D ≈ 23**

Zero-Emissions Aircraft?

- Concepts Included:
  - Hydrogen-fuel (liquid/cryogenic only)

    Fuselage resized to contain all fuel desired range
  - Methane-fuel (liquid/cryogenic only)
  - Nuclear Aircraft (H2 & hydrocarbon fuels)
  - Fuel Cell Powered Electric Aircraft
- Omitted:
  - Battery-Powered (considered too heavy - Take-off power requirements too high)

Zero-Emissions Aircraft?

- **Hydrogen-Fueled Aircraft Assumptions**
  - Put H_2 in fuselage (lengthen as necessary for cargo/pax)
  - Tank and insulation weight = 0.3 X H_2 weight
  - Insulation occupies 30% of possible tank volume
  - Use same gas turbine engine converted to use H_2
  - CO_2 production directly related to HC burned
  - NOx production assumed to be same as typical combustor, corrected by heating value of fuel

	Heat of Combustion BTU / lbm	Density Lbm / ft^3	Energy Density BTU / ft^3
Liquid Hydrogen	49,900	4.4	219,560
Conventional Hydrocarbon (HC)	18,400	50	920,000

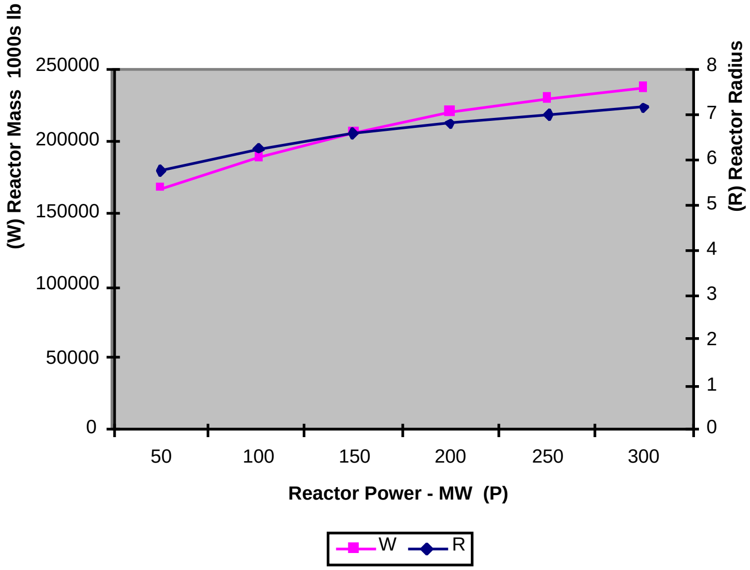
Zero-Emissions Aircraft?

- **<u>Methane-Fueled Aircraft Assumptions</u>**
  - **Put CH_4 in wing (since volume is available)**
  - **Tank and insulation weight = 0.05 X CH_4 weight**
  - **Insulation occupies 15% of possible tank volume**
  - **Use same gas turbine engine converted to use CH_4**
  - **CO_2 production directly related to CH_4 burned**
  - **NOx production assumed to be 75% of comparable HC-fueled combustor**

	Heat of Combustion BTU / lbm	Density Lbm / ft^3	Energy Density BTU / ft^3
Liquid Methane (CH_4)	21,100	26.6	561,260
Conventional Hydrocarbon (HC)	18,400	50	920,000

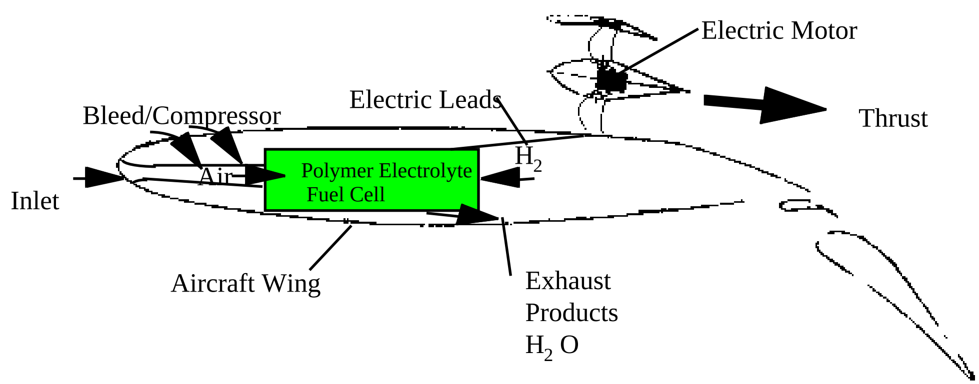
Zero-Emissions Aircraft?

- **Nuclear Aircraft**
  - **Hybrid system - Nuclear reactor supplied heat energy to "conventional" engine at cruise. Fuel used for takeoff/climb and approach/landing (Reactor is cool/safe)**
  - **No CO_2 produced during reactor operation. NOx production assumed same as HC/CH_4 turbofan engine and if no NOx produced during cruise**
  - **NERVA technology assumed, with reactor well shielded to allow "standard" passenger/work environment (low exposure rates) (based on detailed 1960's system studies – no benefit in new technology to reduce shield weight)**
  - **Nuclear reactor designed for long life between "overhauls" (10,000 hours use), heavy, but fairly compact**
  - **Aircraft range almost infinite**



Zero-Emissions Aircraft?

- **Fuel-Cell**
  - **Fuel Cell is used to generate power for electric motors / (propellers/fans) using hydrogen fuel**
  - **Assume Proton Exchange Membrane (PEM) technology being spearheaded by the automotive industry (use in 5-10 years)**
  - **Major weight is fuel cell system @ 0.25 kw/lb (about ten times the weight of the equivalent advanced turbofan system). Fuel cells assumed to weight 4-10 times less than present SOA.**
  - **Advanced (super-conducting) electric motor weighs about 1/2 of advanced turbofans at same thrust**



Zero-Emissions Aircraft?

<u>Results</u>

(at constant 6500 nmi range)

Zero-Emissions Aircraft?

- Liquid hydrogen
  - Bigger but lighter aircraft
  - Operational and engineering challenges to H_2 aircraft (H2 in fuselage)
  - Method of H_2 production (present method very pollutive)
- Liquid Methane
  - In-between kerosene and Hydrogen.
  - Modest reduction in CO_2 and NOx
- Nuclear-powered
  - Weight of reactor dependent on shielding requirements
  - CO_2 depends on fuel (but greatly reduced). NOx production probably substantially less or about equal to base (based on study assumptions)
  - Safety and acceptance difficult
- Fuel cell powered
  - True zero-emissions (depending on source of H2)
  - H2 makes it bigger; fuel cell technology - a heavier aircraft

Zero-Emissions Aircraft?

Future Work

- **Fuel Cells**
  - **Heat load / rejection system weights**
  - **Scaling / sub system weights**
  - **Look at power-handling equipment required, integrate with fuel control to eliminate possible unnecessary items**
  - **Look at physical integration in aircraft structure**